

**“Improving the representation of clouds in general circulation model (GCM) simulations through analysis of cloud resolving model (CRM) results and field data”**

My postdoc at GISS

September 2009-December 2010

Catherine Rio

Agnieszka Mrowiec

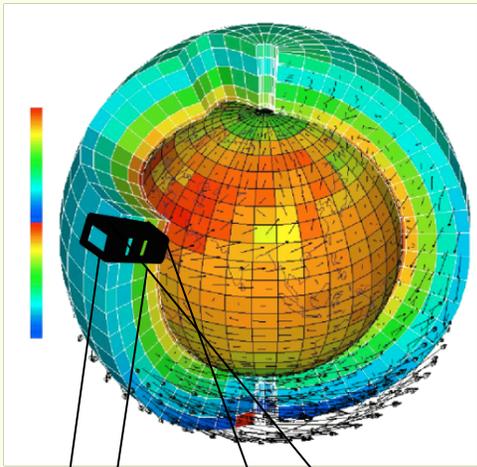
Ann Fridlind, Tony Del Genio

*Thanks to: Andy Ackerman, Audrey Wolf, Mao-Sung Yao*

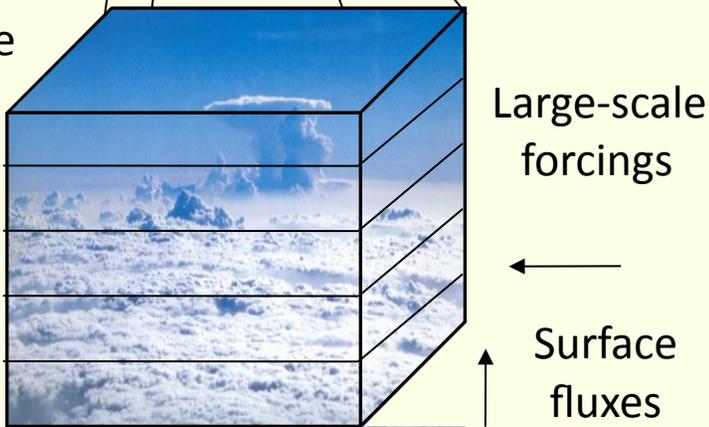
# Methodology

## Development of parameterizations of turbulence, convection and clouds

General Circulation Models  
 $\Delta x = 50-300 \text{ km}$

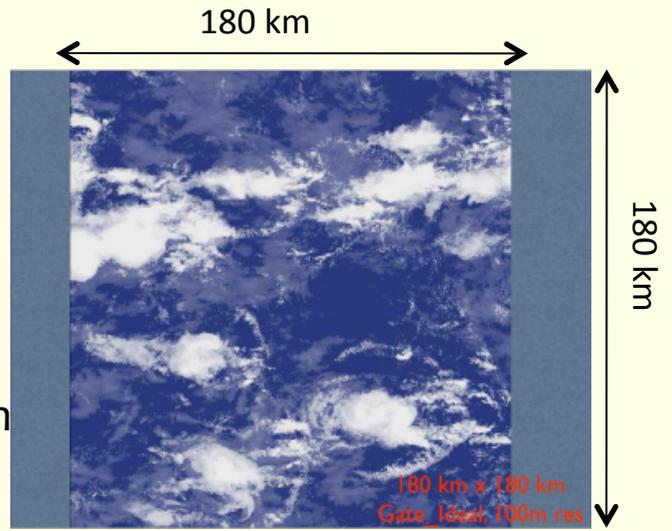


1D mode

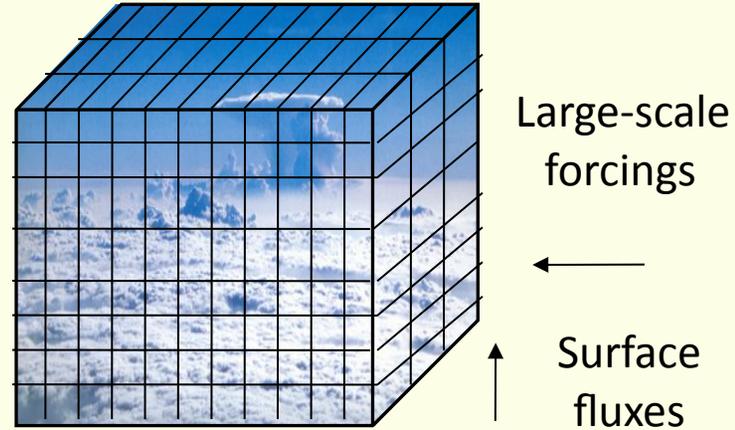


## Cloud process analysis

Cloud Resolving Models  
 $\Delta x = 50 \text{ m} - 1 \text{ km}$



Khairoutdinov, GCSS 2008

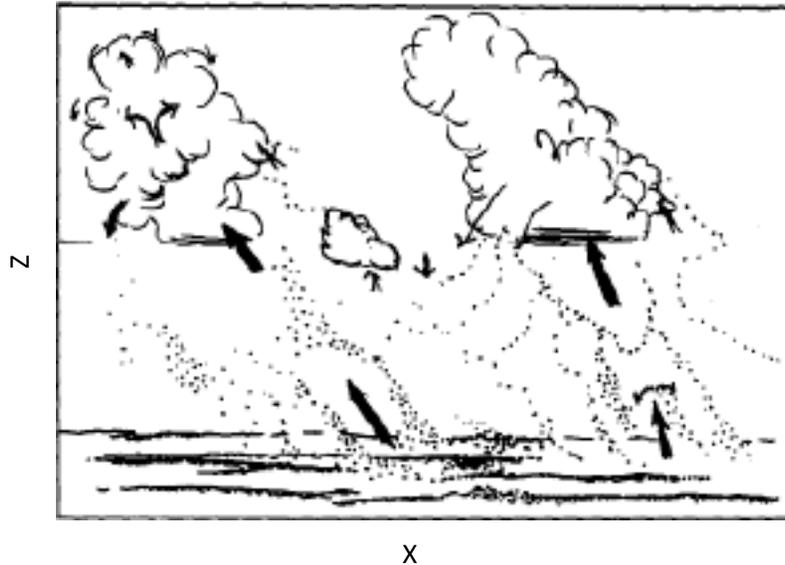


An example

# Boundary-layer clouds

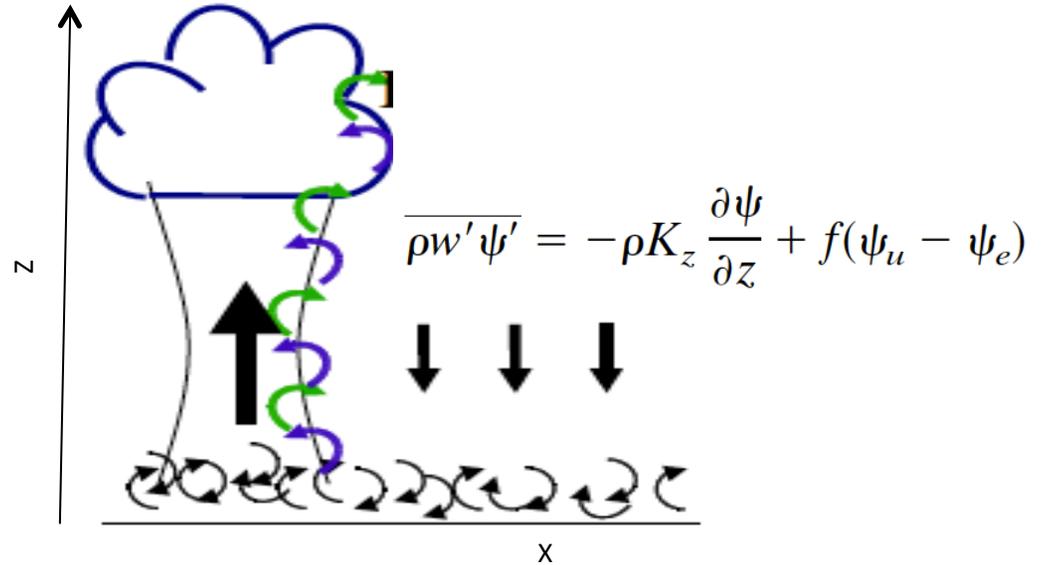
## Schematic view from observations

LeMone and Pennell, MWR, 1976



## Thermal plume model

Rio & Hourdin, JAS, 2008



Conservation equations:

-Mass

$$\frac{\partial f}{\partial z} = e - d$$

-Conserved variables:

$$\frac{\partial f \psi_u}{\partial z} = e \psi - d \psi_u$$

-Momentum:

$$\frac{\partial f w_u}{\partial z} = -d w_u + \alpha g \rho \frac{\theta_{vu} - \theta_v}{\theta_v}$$

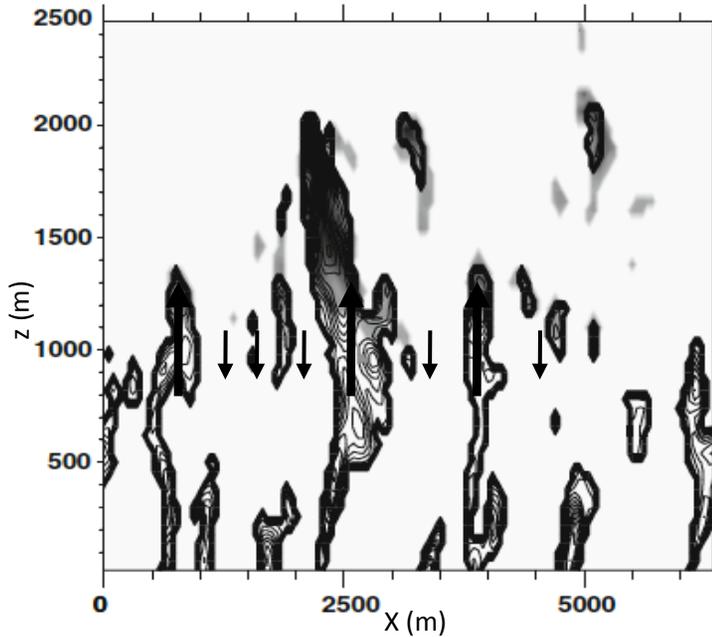
Internal variables:

- Mass-flux f
- Mixing rates: e, d
- Vertical velocity wu
- $\theta_u, q_{vu}, q_{lu} \dots$

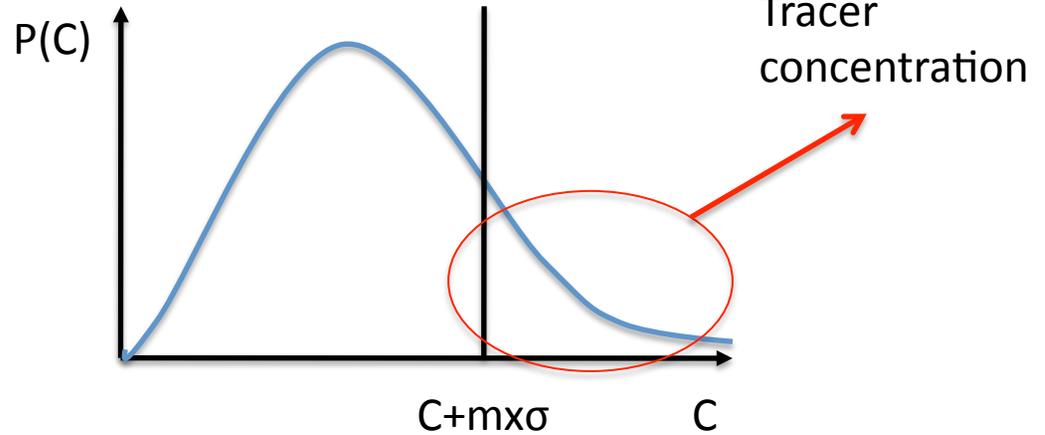
An example

Boundary-layer clouds

How to select thermals in high resolution simulations?



Couvreur & al., BLM, 2010



$$s' > \sigma_s + w > 0$$

↑ ↑ ↑ ↑ ↑ ↑ ↑  
passive tracer emitted in 1<sup>st</sup> layer

Traditional samplings of clouds

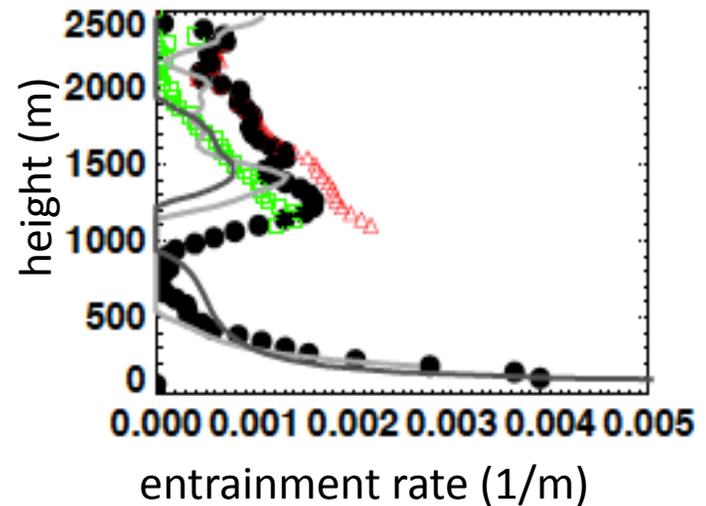
New sampling

$$\varepsilon = \max\left(0, \frac{\beta_1}{w_u} \frac{\partial w_u}{\partial z}\right)$$

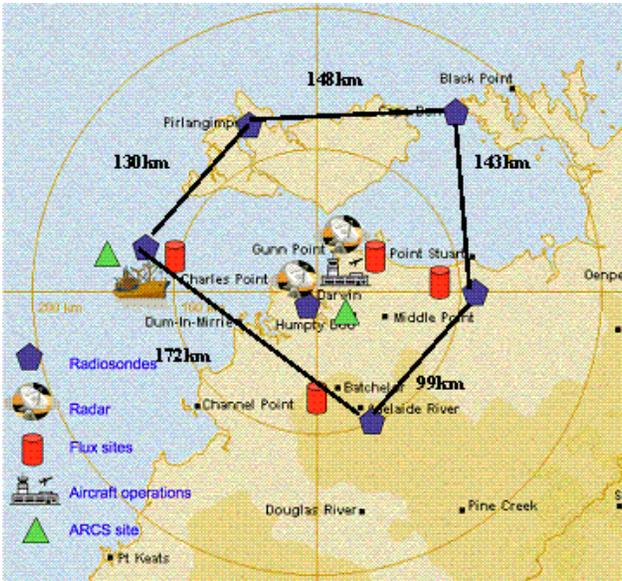
$$\varepsilon = \max\left(0, \frac{1}{1 + \beta_1} \left(a_1 \frac{B}{w_u^2}\right)\right)$$



Rio & al., BLM, 2010



# Intercomparison of CRMs



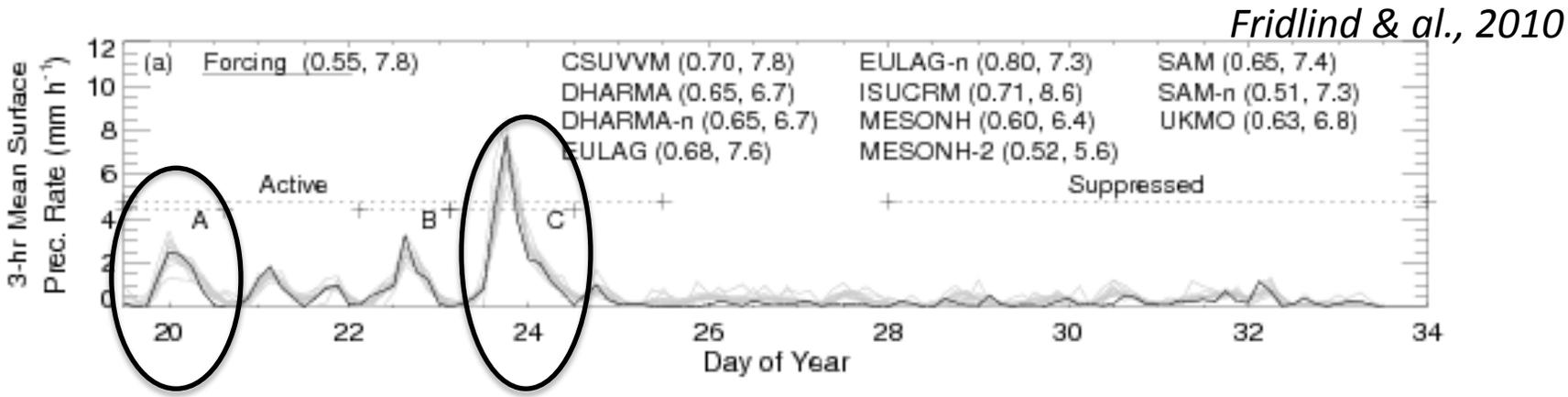
The Tropical Warm Pool-International Cloud Experiment  
 Darwin, Australia  
 January 20 to February 13, 2006

### Observations

- Soundings, surface radiative fluxes, surface turbulence flux

### Variational analysis (Xie & al., JC, 2010)

- vertical velocity, advective tendencies of temperature and moisture

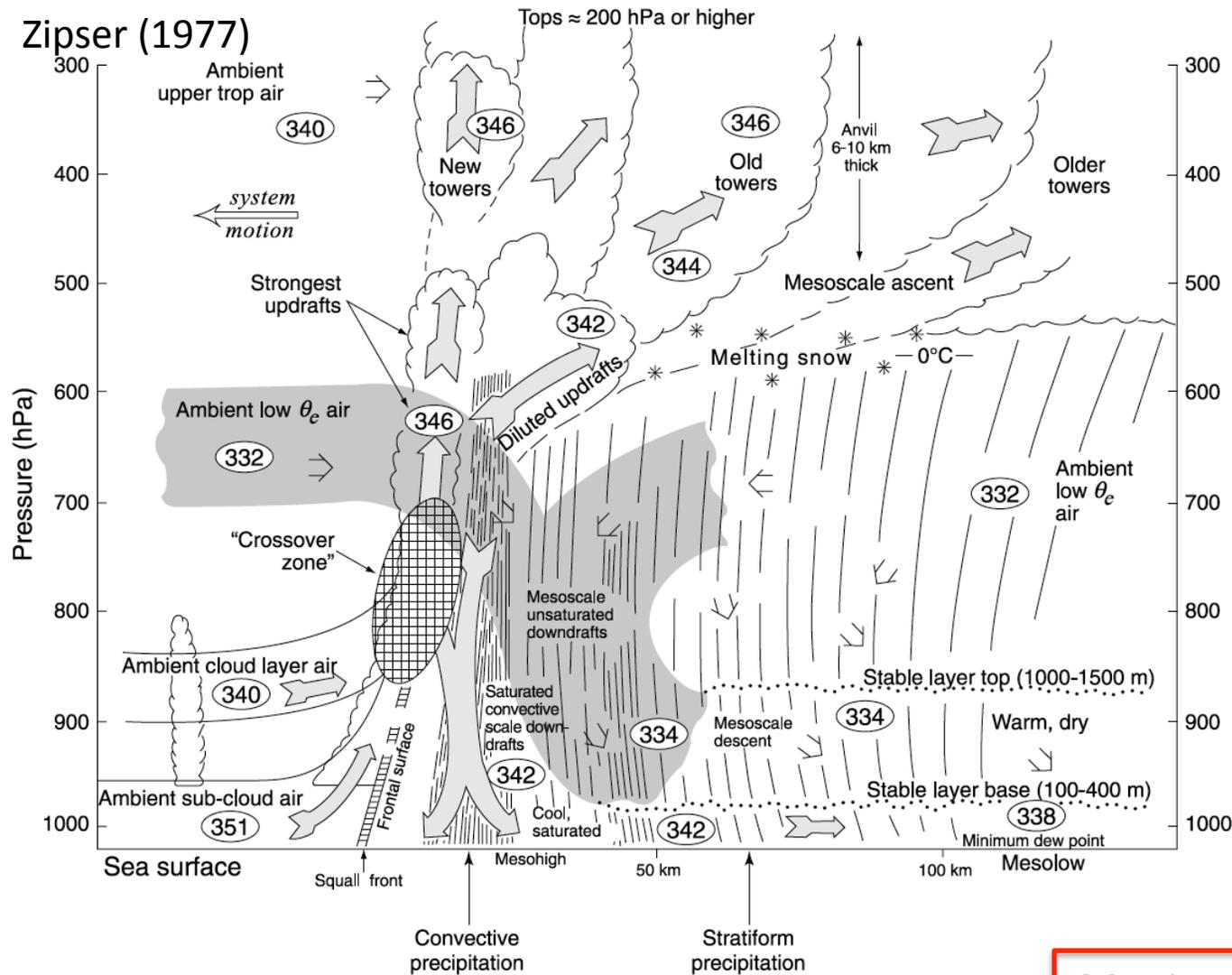


Fridlind & al., 2010

Bench of cloud resolving model simulations: DHARMA, SAM, MESONH, UKMO  
 - different dynamics and sub-grid physics (turbulence, microphysics)  
 -  $\Delta x \sim 1\text{km}$

# Observations

## Observational picture of tropical squall lines



- shallow convection
- Convective scale updrafts and downdrafts
- mesoscale updrafts and downdrafts
- microphysics of clouds
- Cold pools

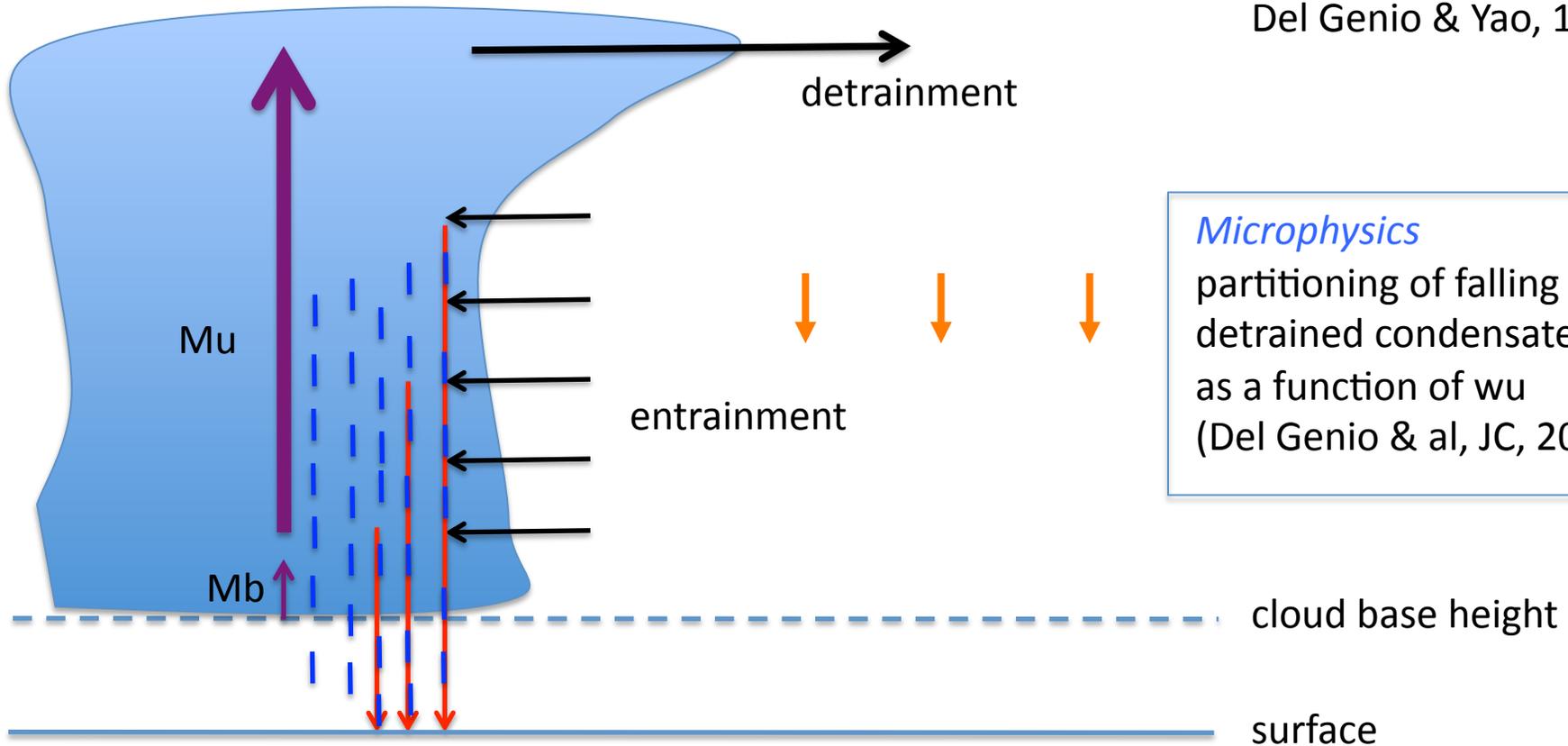
Zipser, JAM (1969), Zipser, MWR (1977), Fernandez, BAM (1982), Houze and Betts, RGSP (1980), Houze, RG (2004), Lemone & Zipser, JAS (1980), Zipser & Lemone, JAS (1980), Lucas et al., JAS (1994), Jorgensen and Lemone, JAS (1989), ...

### GCM issues:

- Heating and moistening profiles
- Rain rates over which area
- Cloud impact on radiation

# Parameterization of deep convection

Del Genio & Yao, 1993



## Microphysics

partitioning of falling and detrained condensate as a function of  $w_u$  (Del Genio & al, JC, 2005)

### saturated updrafts

Conservation equations:

- mass:  $M_u$
- momentum:  $w_u$
- dry static energy:  $\theta_u$
- moisture:  $q_v$
- internal variables:  $E, D, M_b$

### downdrafts

Conservation equations:

- mass:  $M_d$
- dry static energy:  $\theta_d$
- moisture:  $q_v$
- Internal variables:  $E, D, M_d$
- $M_d_{ini} = 1/3 M_u$

### Compensating subsidence

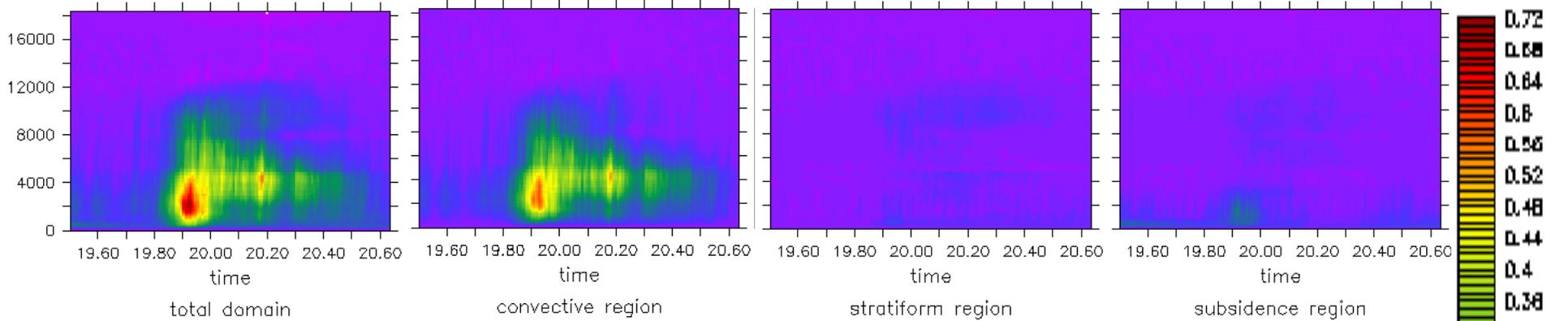
in the environment



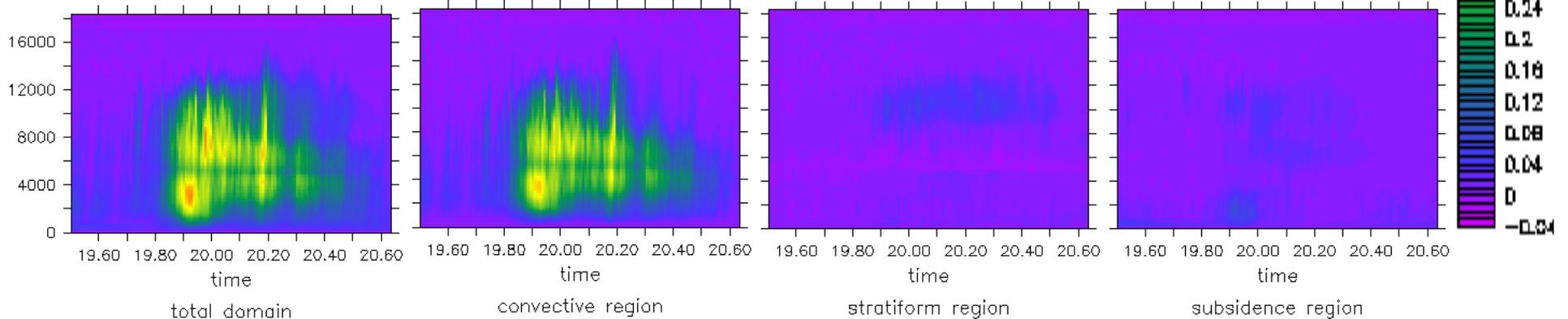
# Convective/stratiform partitioning

## Event A - DHARMA

MSE flux (K m/s)  $MSE = CpT + gz + Lvqv - Lfqic$



qt flux (g/kg m/s)



- Major part of fluxes occurs in the convective region
- In the stratiform region: fluxes within the anvil and below
- In the subsidence region: dry and shallow convection transport

# Traditional samplings of updrafts and downdrafts

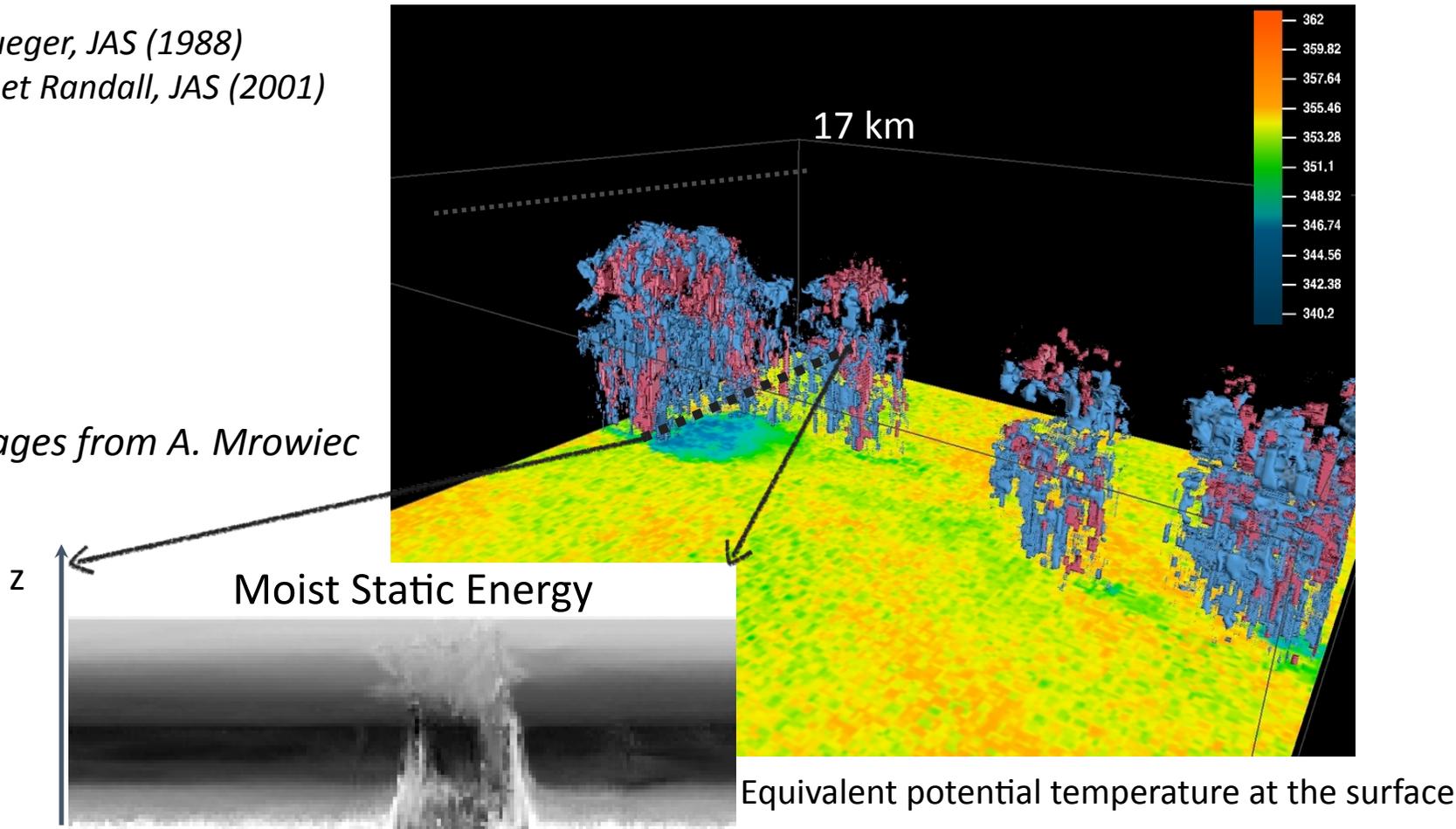
**Cloudy updrafts:** condensate (liquid and ice) + positive  $w$  threshold

**Precipitating downdrafts:** precipitation (rain and graupel) + negative  $w$  threshold

*Krueger, JAS (1988)*

*Xu et Randall, JAS (2001)*

*Images from A. Mrowiec*



\*Visualization made using 

**Limitations:**  
do not allow to differentiate convective scale transport from local transport or gravity waves

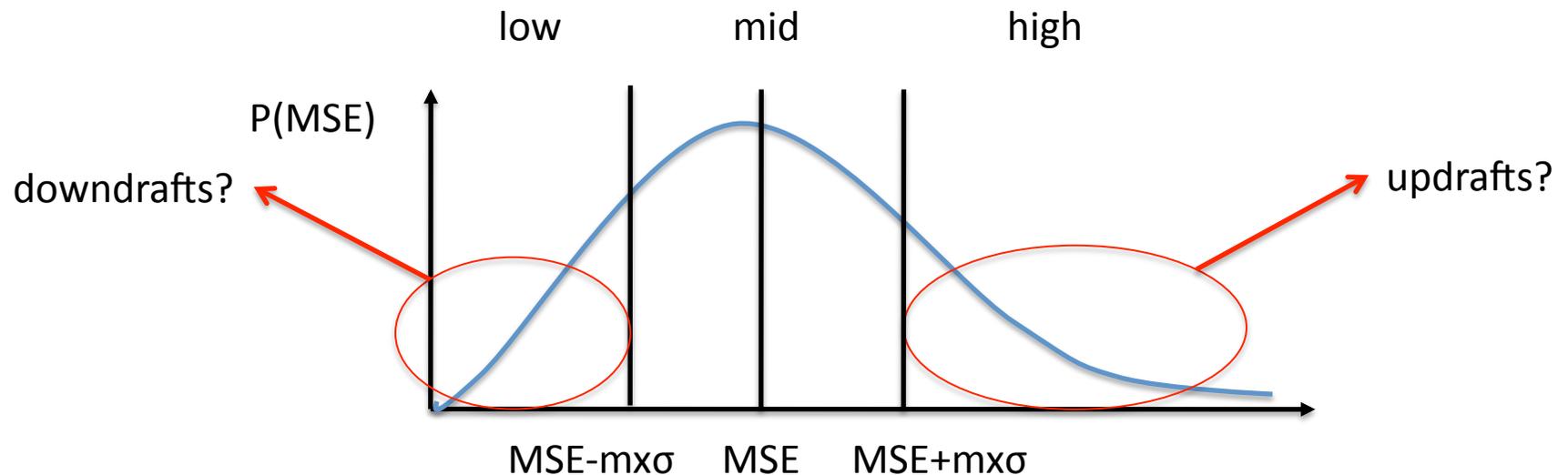
## A MSE sampling of updrafts and downdrafts

A **sampling** based on the observational evidence that:

- Updrafts transport high  $\theta_e$  or moist static energy (MSE) up
- Downdrafts transport low  $\theta_e$  MSE down (Zipser, 1969; Betts, 1976 ...)

At a given (z,t):

✓ MSE threshold:

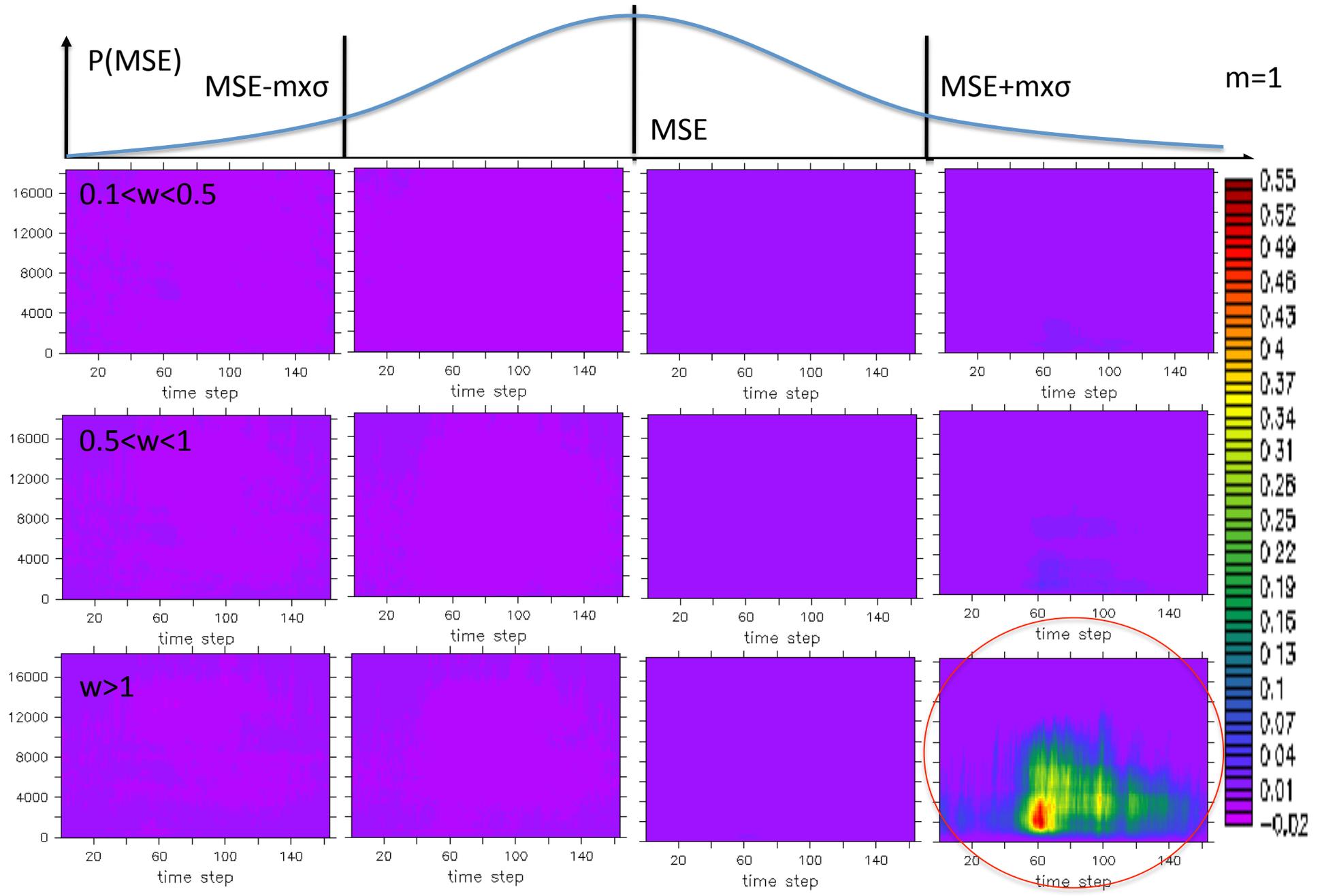


✓ Vertical velocity threshold?

3 categories: 0.1-0.5-1m/s

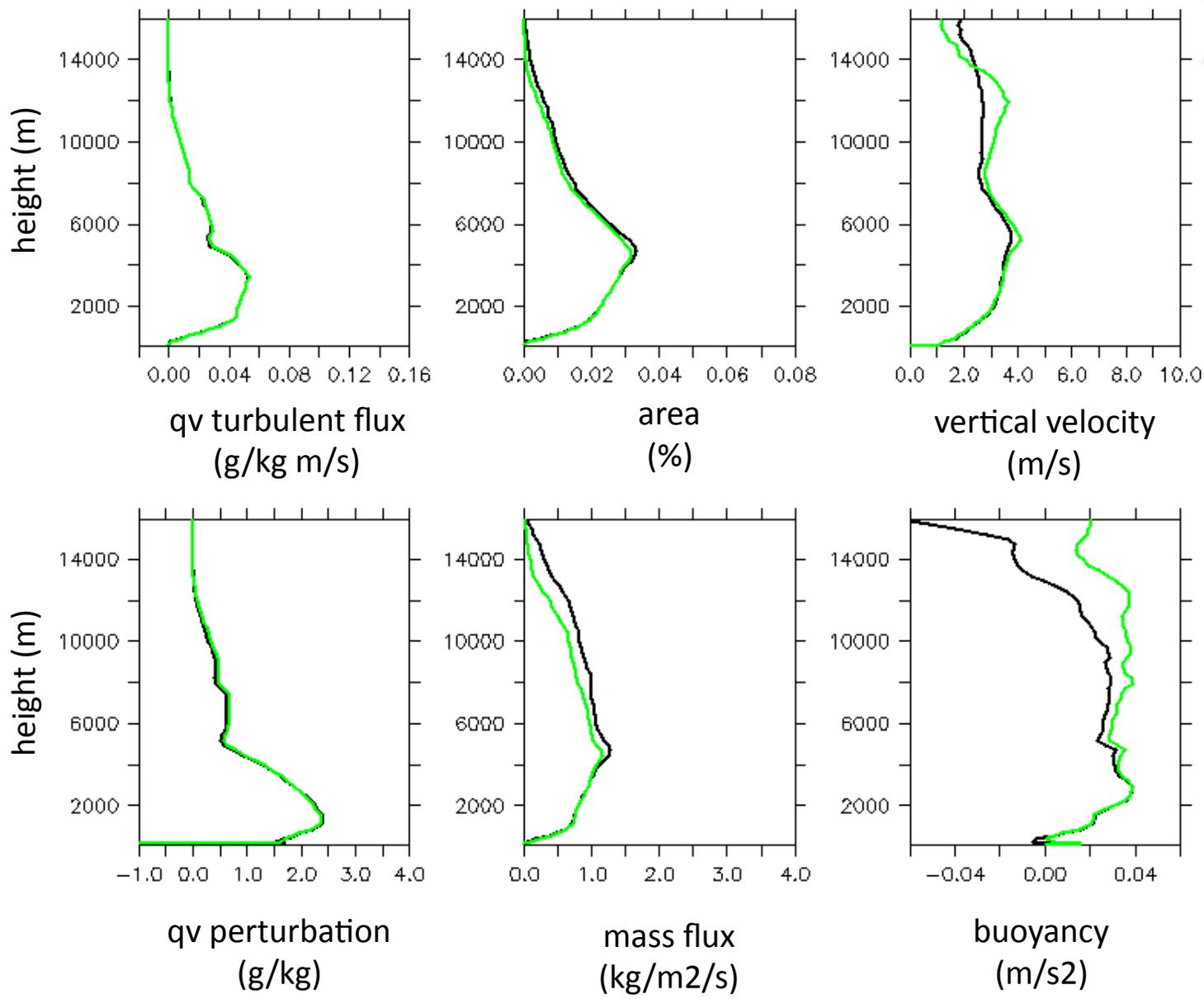
CRM

# Updraft categorization in the convective region



# Updraft properties

## Event A - DHARMA



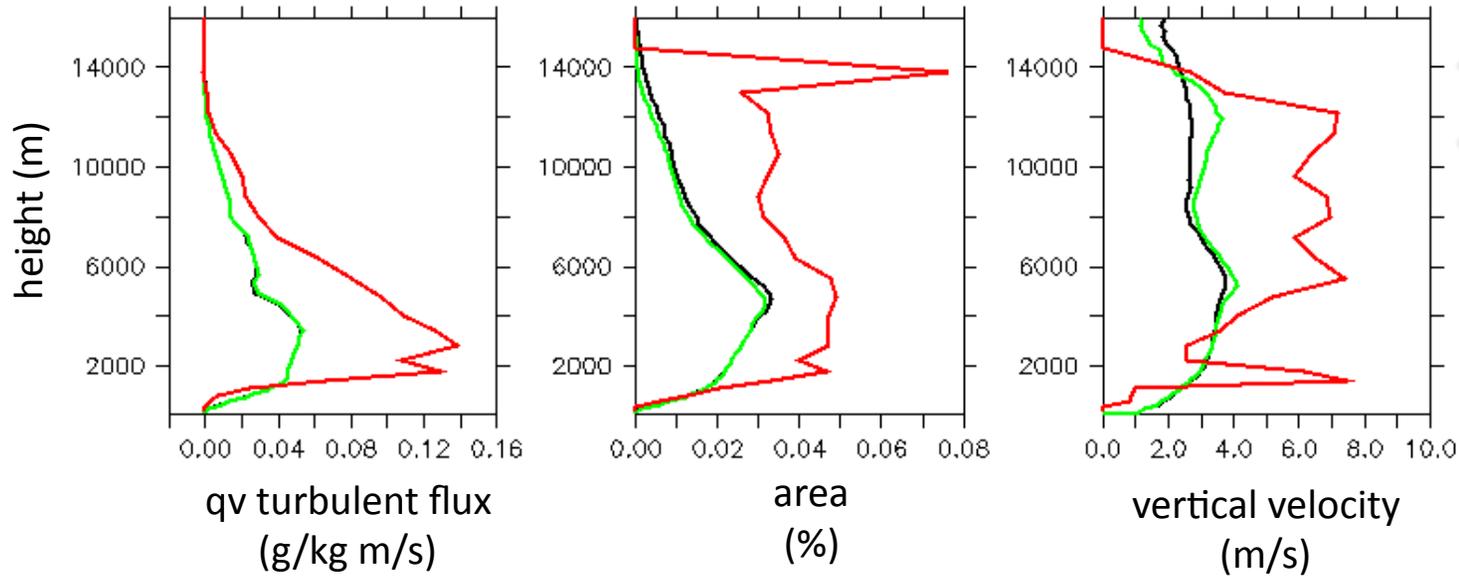
— cloudy updrafts  
— high MSE updrafts

MSE sampling:  
- same qv flux  
- with less points

Selected updraft:  
-moister  
- faster  
- higher buoyancy

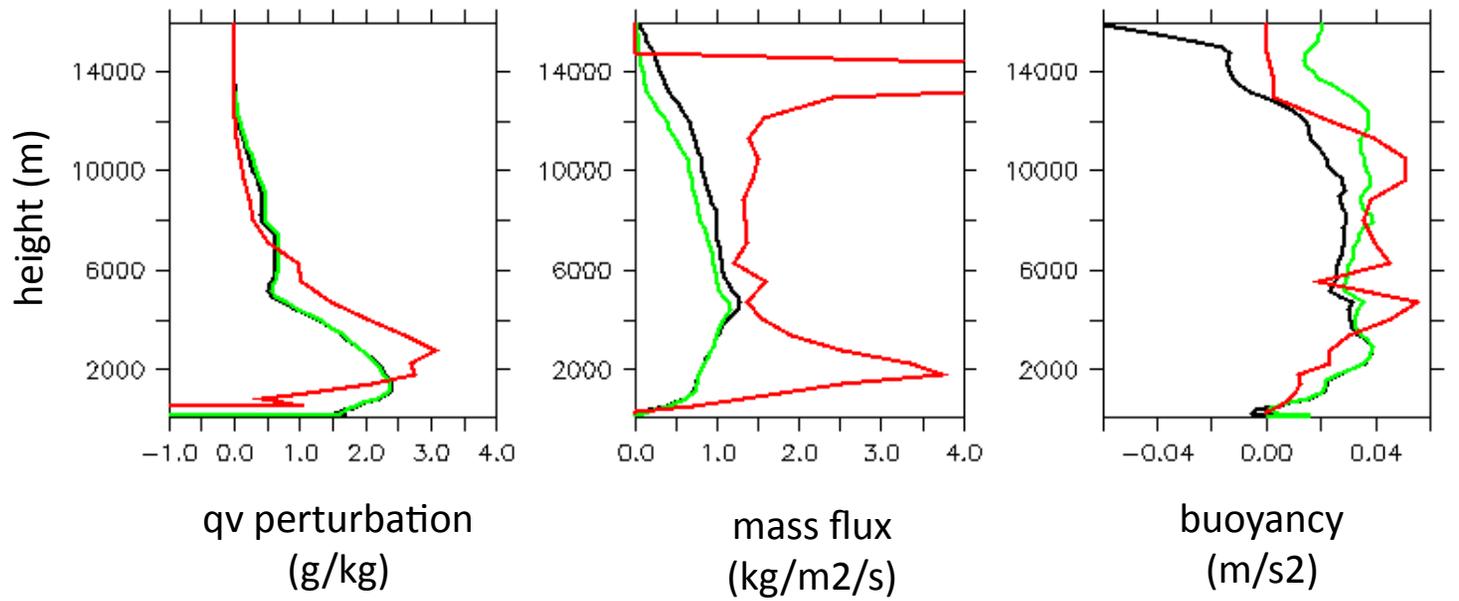
# Updraft properties

## Event A - DHARMA



- cloudy updrafts
- high MSE updrafts
- GISS updrafts

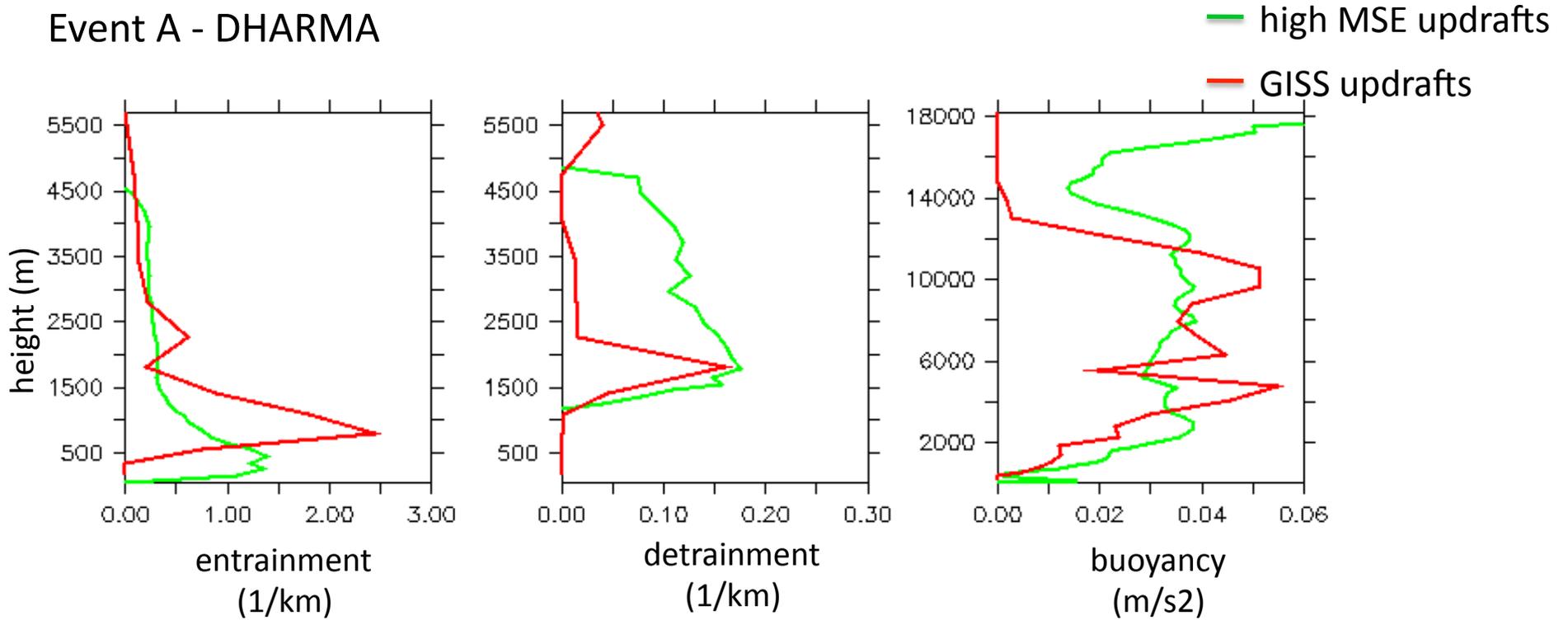
Overestimated  
- mass-flux  
- vertical velocity



Related processes:  
- Entrainment  
- P perturbations  
- Detrainment

## Parameterization issues

Event A - DHARMA



$$\epsilon = \frac{1}{\psi - \psi_u} \frac{\partial \psi_u}{\partial z}$$

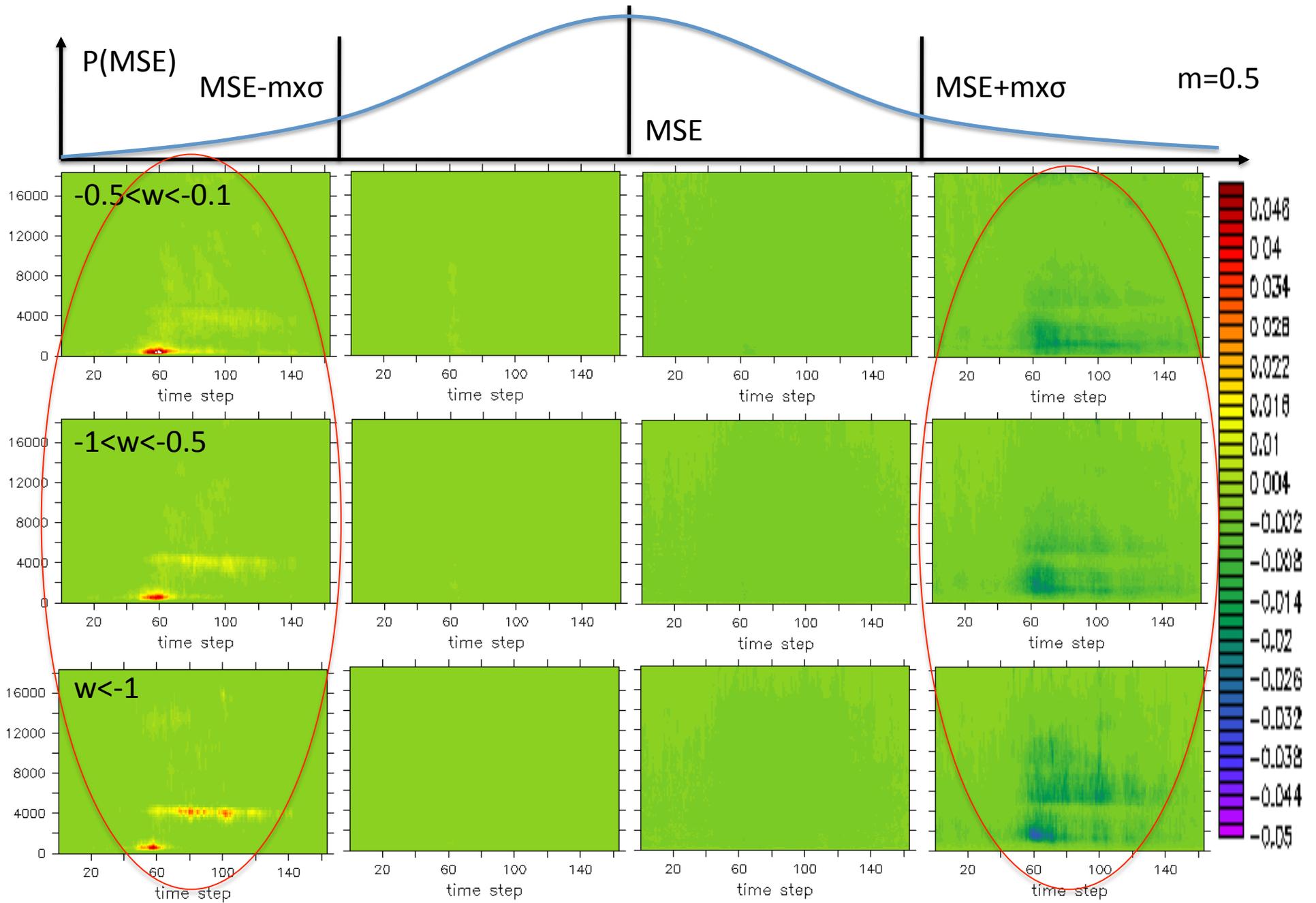
$$\delta = \frac{-1}{f} \frac{\delta f}{\delta z} + \epsilon$$

$$\frac{1}{2} \frac{\partial w_u^2}{\partial z} = a_1 B - a_2 \epsilon w_u^2$$

- Entrainment overestimated at low levels
- Detrainment underestimated above 2km
- Buoyancy ok > underestimation of pressure perturbation impact on velocity field

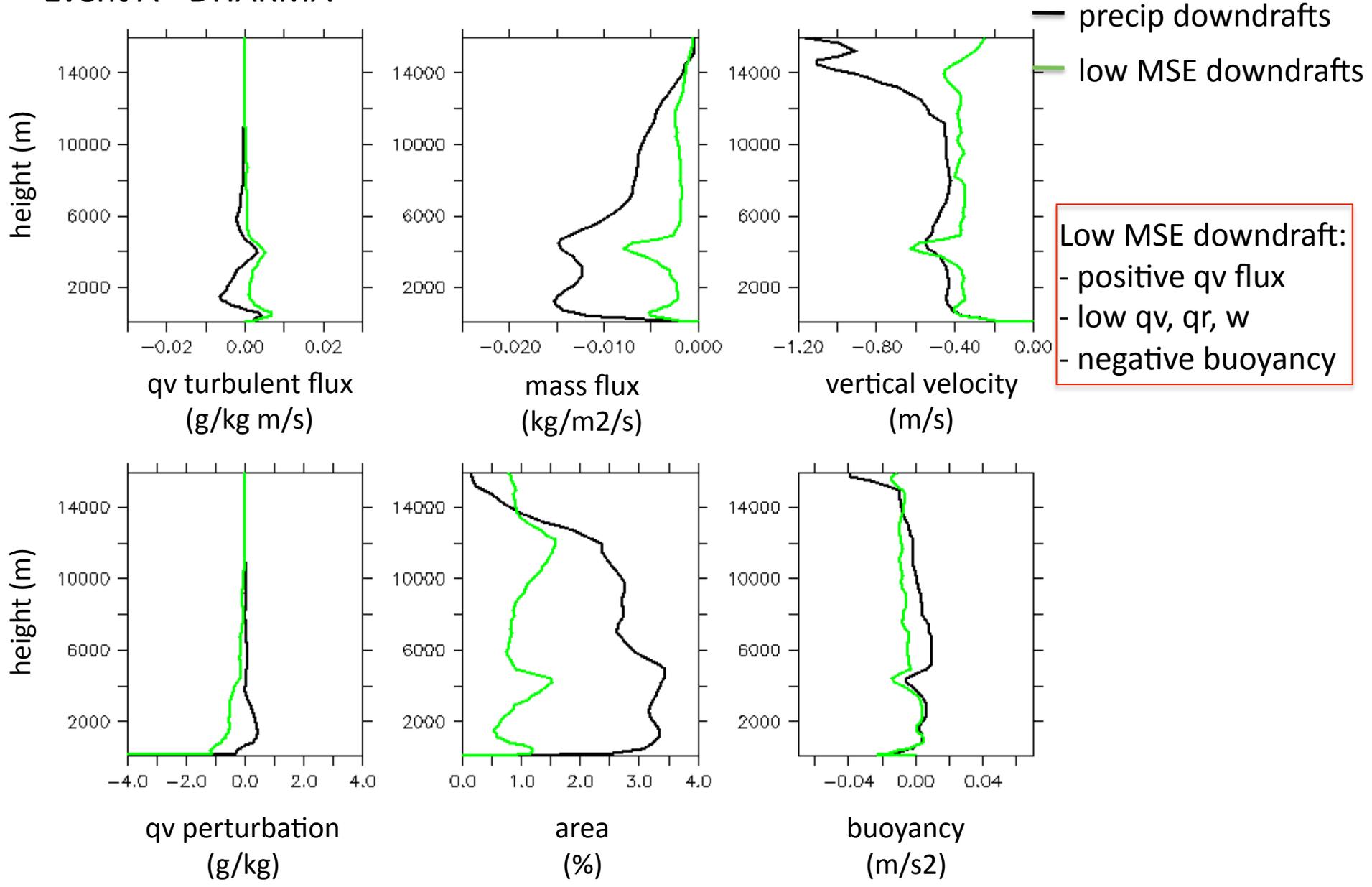
CRM

# Downdraft categorization in the convective region



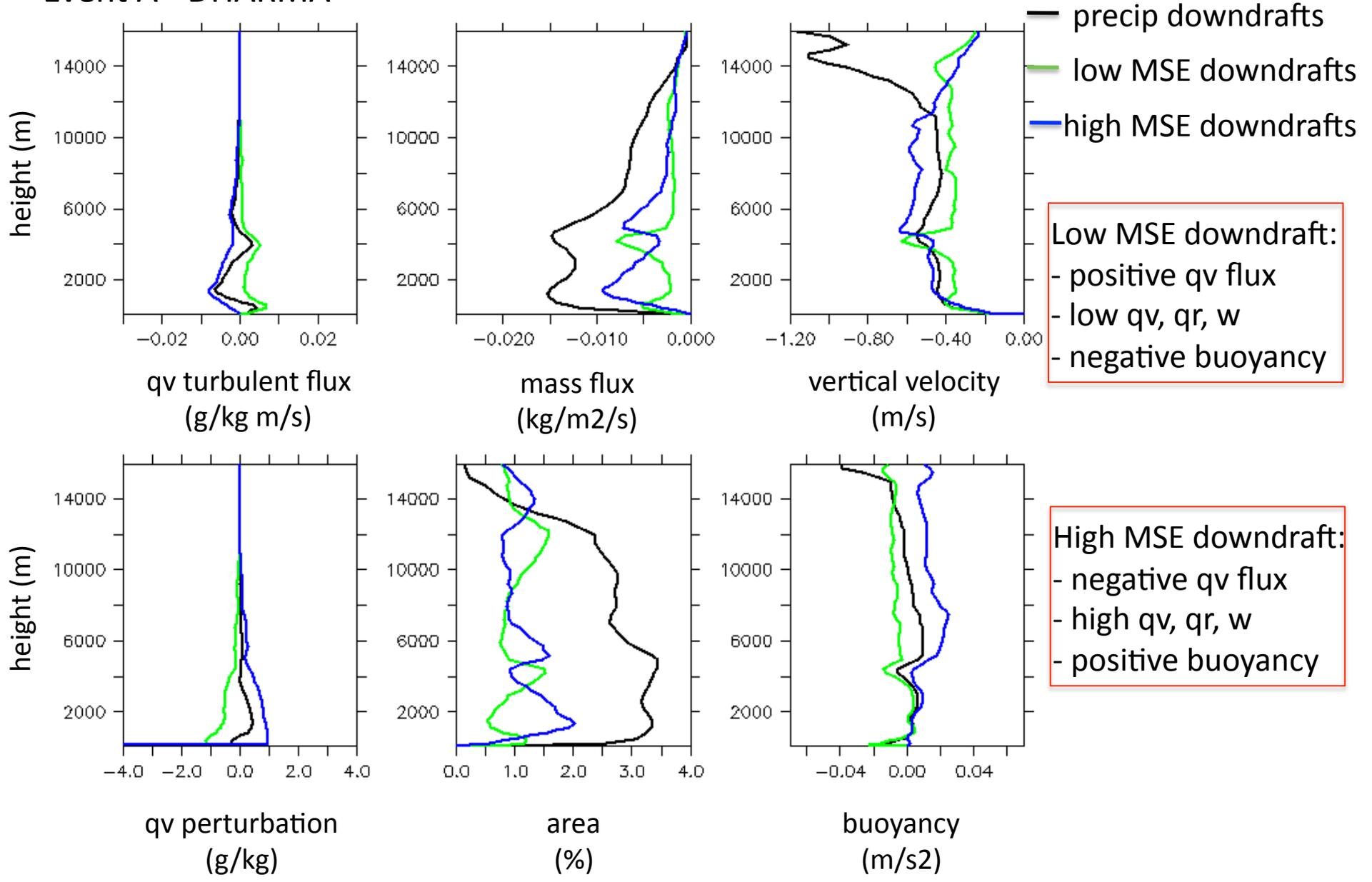
# Downdraft properties

Event A - DHARMA



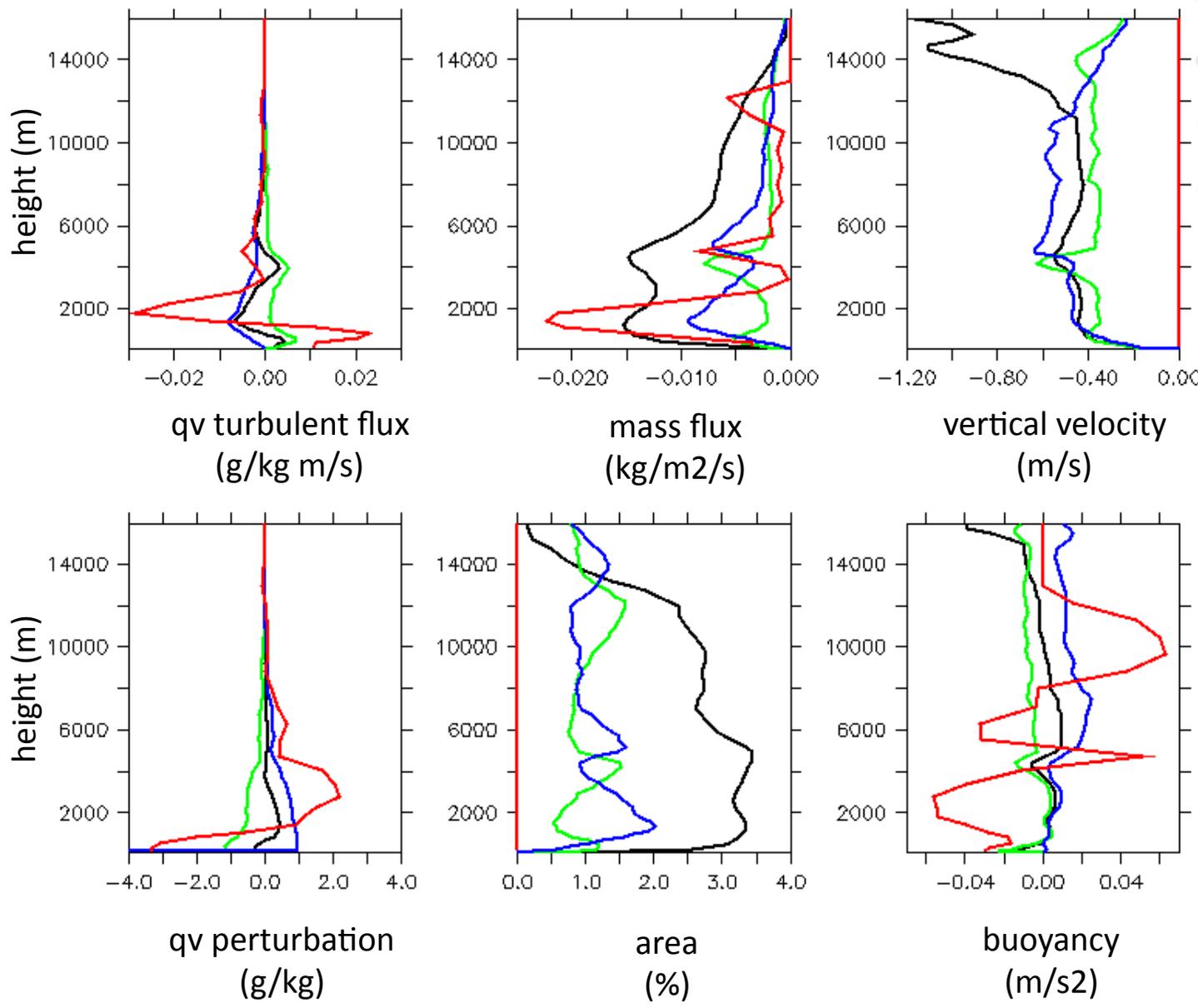
# Downdraft properties

## Event A - DHARMA



# Downdraft properties

## Event A - DHARMA



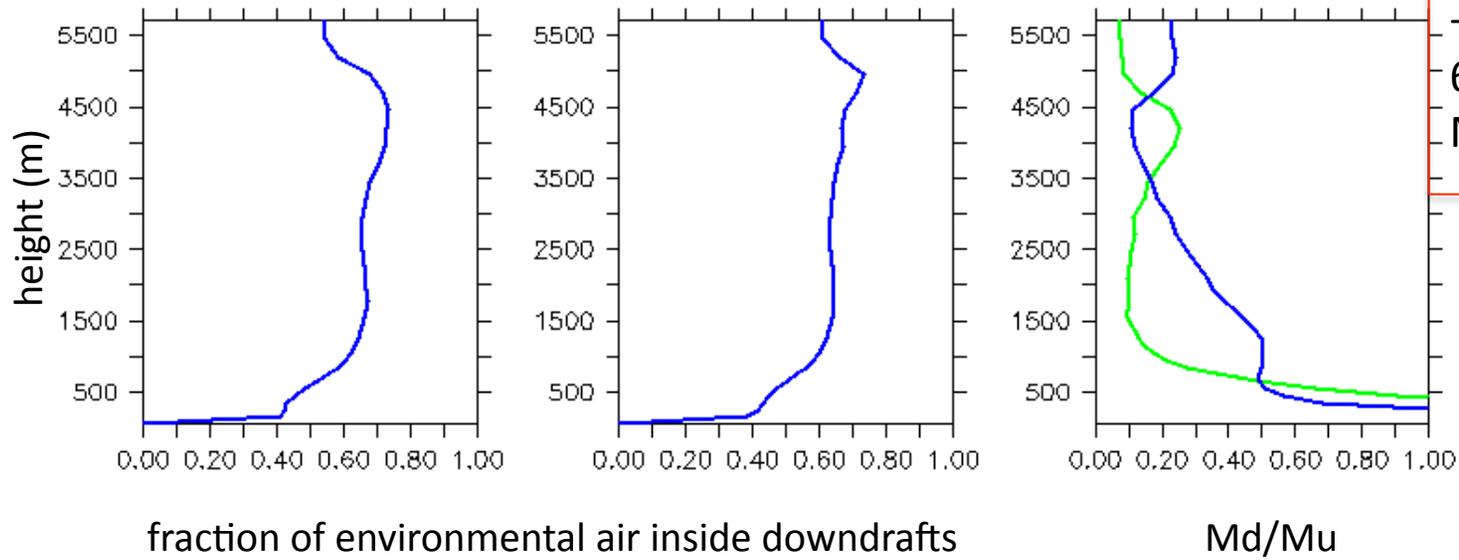
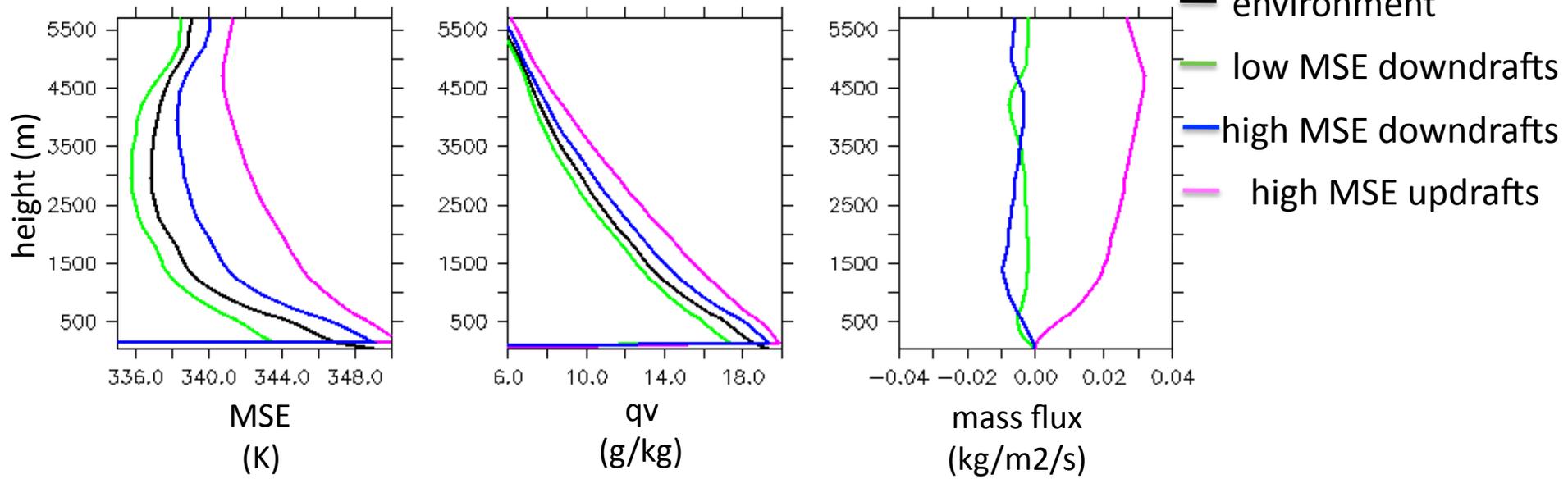
- precip downdrafts
- low MSE downdrafts
- high MSE downdrafts
- GISS downdrafts

- overestimated mass-flux  
 - Above cloud base: high MSE downdraft  
 - Below cloud base: low MSE downdraft

Related processes:  
 - downdraft initiation  
 - downdraft mass-flux at initiation level  
 - entrainment  
 - detrainment  
 - vertical velocity equation?

# Parameterization issues

## Downdraft initiation



-High MSE downdrafts:  
60%env – 40% up  
Md: 20 to 40% of Mu

CRM

# Structure visualization

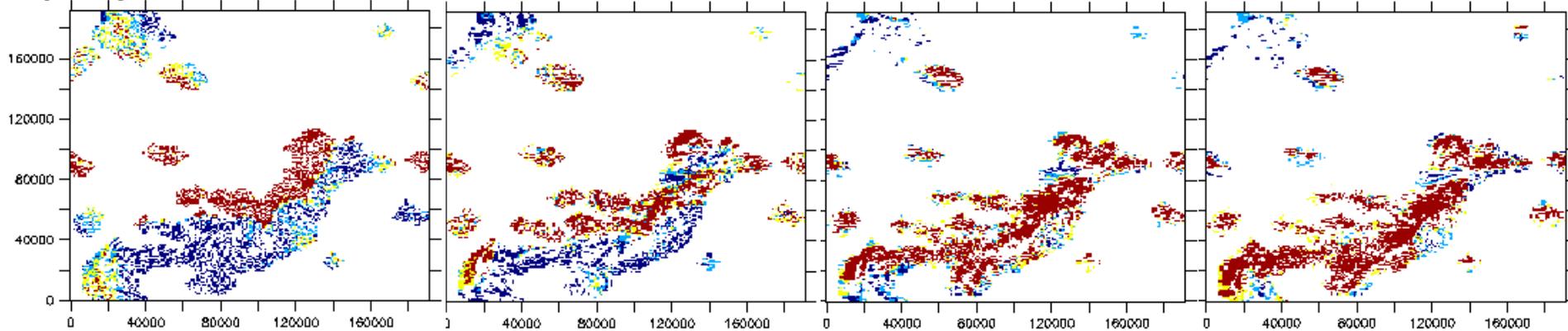
Event C - SAM

**Updrafts** 150m

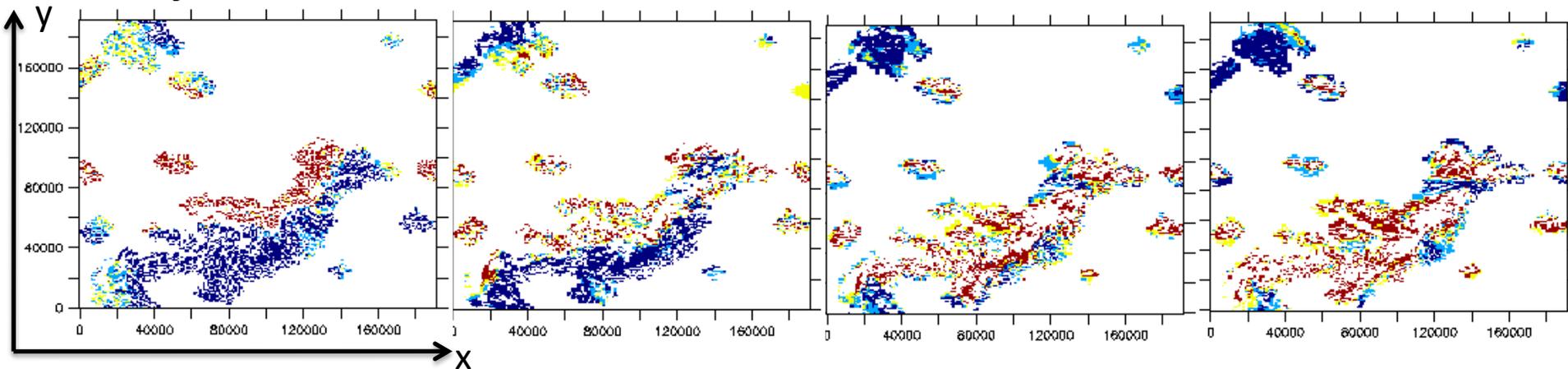
1km

2km

4km



**Downdrafts**



low MSE

mid-low MSE

mid-high MSE

high MSE

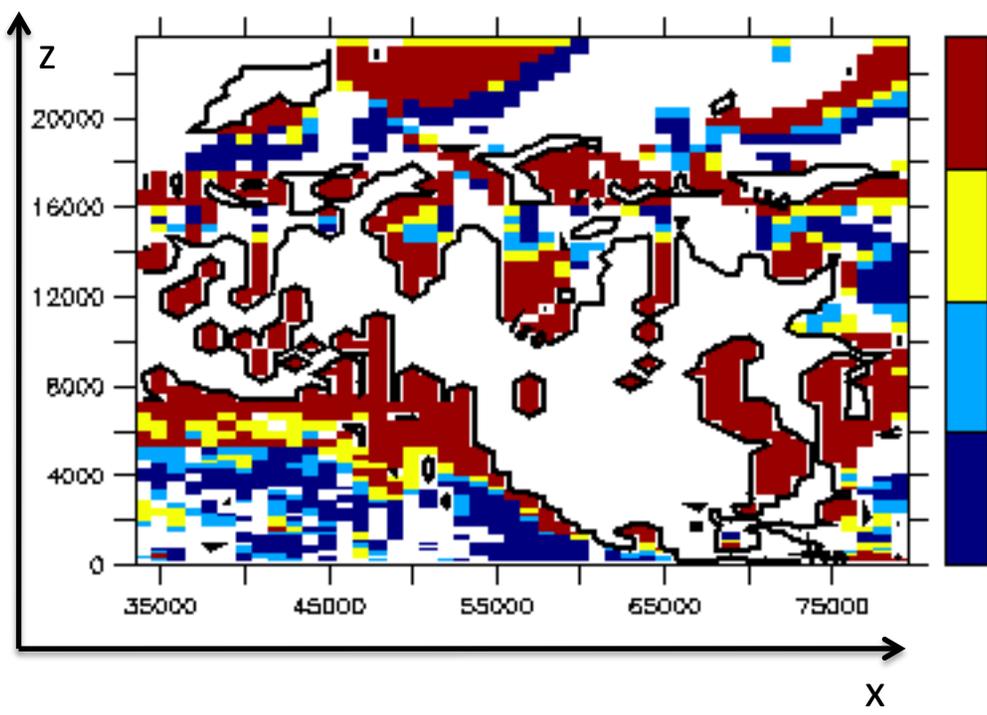
-High MSE downdrafts right under cloud base

-Low MSE downdrafts at low levels under the tilting updrafts

CRM

# Structure visualization

Event C - SAM



Are they the same structure from 8km to the surface?

high MSE

mid-high MSE

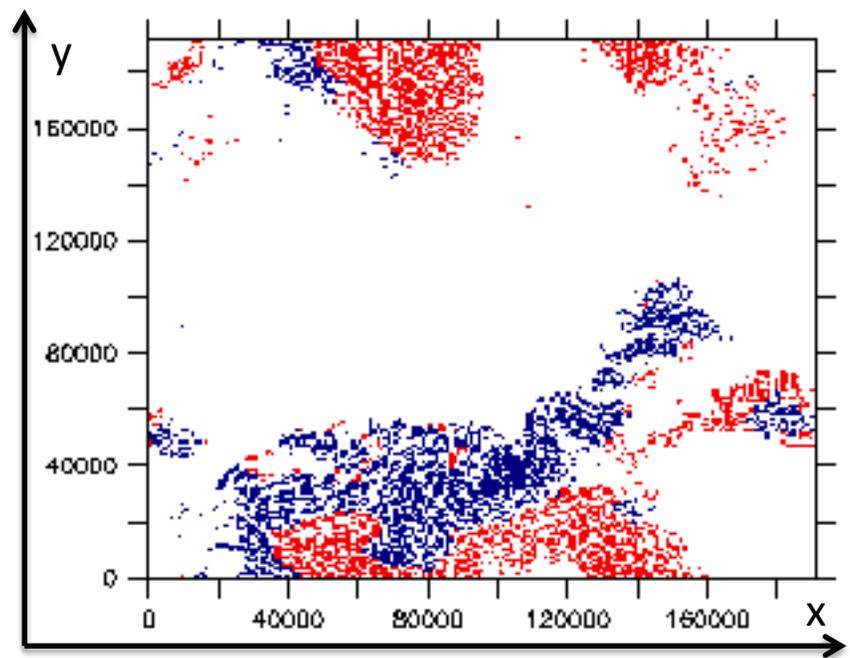
mid-low MSE

low MSE



low MSE strat

Low MSE downdrafts spread into the stratiform region  
**Low MSE downdrafts = cold pools?**



## Conclusions

# “Improving the representation of clouds in general circulation model (GCM) simulations through analysis of cloud resolving model (CRM) results and field data”

1. Identify a key physical process in clouds life cycle that matters at global scale

*Downdrafts: strongly modify the boundary layer + deep convection triggering*

2. Understand the mechanisms behind this process from observations or high resolution modeling

*Water loading, melting, evaporation, mixing*

3. Evaluate existing parameterizations

*Parameterization hypothesis: downdraft initiation, mass-flux, microphysics*

4. Develop or improve parameterizations

5. Run GCM and study the impact of the development at global scale

6. Identify GCM weaknesses

*Long is the road...*